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JET STITCHING OF BATT

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This invention relates to novel textile products and to a process for their production. More particularly, it relates to non-woven fabrics, textile composites, yarns and the like and to their production by subjecting bulk fibrous materials to the action of fluid forces. In still another aspect, it relates to the production of improved woven and knitted fabrics.

The prior art discloses various processes in which fluids under pressure have been used to treat textile materials. Thus, for example, binder solutions have been sprayed onto fibrous webs, which are subsequently dried to effect bonding. Fabrics and the like have been subjected to the action of streams of water or the like in various washing or cleaning processes. Dispersed streams of water, provided by a solid cone spray nozzle supplied with water at 70 to 100 lbs./sq.in. pressure, have been applied through spaced apertures against a fibrous starting material so as to rearrange laterally the individual fibers into a pattern determined by the pattern of the apertures.

An object of the present invention is to provide a process for the direct conversion of bulk fibrous materials into coherent, highly stable textile products without using conventional process steps such as weaving, knitting, twisting, or the like and without the need for special bonding agents or materials. Another object of this invention is to provide a process for stitching seams in bulk fibrous materials or for stitching fibrous materials

to a suitable substrate without the use of conventional sewing techniques. A further object of this invention is to provide a process for improving the properties of woven or knitted fabrics. A still further object of this invention is the provision of new and useful textile products.

These and other objects of this invention will become apparent in the course of the following specification and claims.

The process of this invention involves subjecting fibrous sheet materials to the action of one or more fine, columnar streams of a non-compressible fluid, projected against the surface of the fibrous structure with sufficient force to drive individual fibrous elements of the material into an interentangled relationship with other fibrous elements in all dimensions of the structure. The individual streams are preferably of sufficient fineness to produce the desired filament interentanglement without permanently separating groups of fibers, i.e., without forming openings in the sheet.

By "interentangled" is meant that the individual fibers of the sheet are intertwined, tangled, interlaced and otherwise joined with each other so as to be virtually inseparable. The process may be applied to preselected areas of the fibrous sheet material up to and including its entire area.

By "fibrous sheet materials" is meant any sheet-like structure composed of textile filaments in the form of staple fibers, continuous filaments, or yarns whether in the form of loose batts, webs and the like or in the form of woven, knitted or non-w ven fabrics, and including layered ~~composites~~ thereof.

Briefly the process of this invention may be operated as follows: Water or other suitable liquid is forced under high pressure through a nozzle or series of nozzles to form the fine, columnar high velocity stream or streams. The fibrous sheet material to be treated is placed on a suitable support, preferably a screen or other foraminous member and passed, sheet side up, under and close to the nozzle so as to be traversed by the fluid stream or streams. In effect, each columnar stream thus traverses the fibrous sheet along a path in the direction of movement of the sheet. Wherever the columnar stream acts on the sheet, individual fibers in the sheet are forced into an interentangled relationship with each other in all dimensions of the sheet. A single stream, or a multiplicity of streams spaced a preselected distance apart, depending on the effect desired, may be applied continuously or intermittently to the sheet material in a direction perpendicular or oblique to its surface. The fibrous sheet material may be subjected to a number of passes to increase the intensity or area of interentanglement. The fibrous sheet material may be treated along its lengthwise direction and/or transversely and/or obliquely thereto. The fibrous sheet material may be treated from one side only or from both sides, the latter being carried out either in successive steps or simultaneously. The products of this invention are characterized by a three-dimensional fiber-interentanglement, extending in lineal fashion corresponding to the path of traverse of the fluid stream and extending in preselected areas up to and including the entire area of the sheet material.

The process of this invention may be used to produce a wide variety of products. It is especially suitable for the direct conversion of bulk fibrous materials into

textile products having the hand, drape, and strength of conventional woven fabrics. Thus, loose batts, mats, webs, and the like composed of ~~staple fibers~~ and/or continuous filaments may be converted directly into coherent, stable non-woven fabrics by subjecting such batts to the action of high velocity fluid streams over substantially their entire area. Particularly strong non-woven fabrics are obtained by treating substantially the entire area of a composite structure composed of an intermediate layer consisting of two warps of parallel yarns or continuous filaments arranged so that the yarns of one warp cross the yarns of the other warp and a cover layer consisting of a batt of loose staple fibers or continuous filaments, on one or both sides of the intermediate layer. The resulting structure consists of a layer of crossed yarn or filament warps held together by staple fibers or continuous filaments, which have been forced back and forth through the structure by the action of the high velocity fluid streams.

Non-woven fabrics having particularly high levels of drape and conformability may be obtained by using crimpable, spontaneously elongatable, or elastic fibers as one of the components of the fibrous sheet material and developing the latent properties of the fiber after formation of the non-woven fabric as above.

By proper control of process conditions, discrete seams may be produced in bulk fibrous materials, such as staple fiber batts, each seam consisting of an area of high fiber entanglement corresponding to the path of traverse of the high velocity fluid stream or streams. A series of such discrete seams may be formed in a loose mat, batt, web or the like according to any predetermined pattern to produce quilt-like structures. Yarns may be produced by forming straight seams in a bulk fibrous material by the process of this inventi n, and subsequently cutting the seam from the structure. Such yarns have the feel, cohesion, and strength f yarns produced by conventional spinning processes.

The high velocity fluid streams may also be used to stitch conventional fabrics together, attach batt materials and yarns to themselves and/or to conventional woven fabrics or foam-type backings and to convert piddled continuous-filament waste yarn into non-woven fabrics. The process of this invention may also be used to modify the properties of conventionally produced woven or knitted fabrics to improve their appearance, hand, tactile properties, covering power and the like.

The process of this invention may be more thoroughly understood by the following discussion, with reference to the accompanying drawings wherein

Figure 1 shows a schematic view of one type of apparatus for carrying out the process of this invention.

Figures 2a-2o are axial cross-sectional views of suitable nozzles.

Figure 3 is a cross-sectional view, taken along the longitudinal axis, of a nozzle which may be used to produce intermittent columnar flow.

Figure 4 is a schematic view of an alternative apparatus for carrying out the process of this invention.

Figure 5 is a schematic isometric view of an apparatus for the high speed production of a continuous non-woven fabric.

Figure 6 is a schematic isometric view of an apparatus for the high speed production of continuous chenille-type yarns.

Figures 7a-7c are diagrammatic representations of cross sections of a batt of fibers at three stages of treatment.

Figure 8 shows a seamed batt produced by the process of this invention.

Figures 9a and 9b show a quilted batt before and after shrinking.

Figure 10 shows chenille-type yarns produced by the process of this invention.

Figure 11 shows a staple batt stitched to a fabric.

Figure 12 shows a continuous filament web attached to a fabric.

In carrying out the process of this invention, fibrous sheet materials are subjected to the action of high velocity, columnar fluid streams, which latter may be continuous or intermittent.

Referring to Figure 1, nitrogen under a pressure of 2000 lbs./sq./in. in a bottle 1 is connected through a regulating valve 2 and pipe 3 to one chamber 4 of a hydraulic accumulator 5. The hydraulic accumulator is separated into two chambers 4 and 6 by a flexible diaphragm 7. The second chamber 6 is connected to a nozzle 20 through a pipe 8 in which a valve 9 is provided. Water is supplied to the second chamber from a source of water (not shown) through a valve 10 and a pipe 11. When water is added, pressure is released from the first chamber through pipe 12 by opening a valve 13. Starting with an unpressurized situation, the system is charged by closing regulating valve 2, opening valve 13 so that atmospheric pressure prevails in the system, closing valve 9 and opening valve 10 to admit water at a pressure of about 40 lbs./sq. in. gauge; the water pushes the diaphragm 7 of the accumulator 5 to the right into chamber 4, thus filling chamber 6. After chamber 6 is filled, valves 10 and 13 are closed, regulating valve 2 is opened and adjusted to deliver nitrogen at about 2000 lbs./sq. in. gauge to the chamber 4; this pressurizes the water in chamber 6 so that the system is ready to deliver water to the nozzle 20 through line 8 whenever valve 9 is opened.

The fluid nozzle 20 may be any one of a variety of nozzles depending on the effect desired. Various types of nozzles which may be used are shown in Figures 2a-2c.

The fibrous sheet material to be treated 14 is placed on a generally rectangular wire screen carrier 15 situated below the vertically disposed nozzle 20 and supported on a horizontal, flat metal plate 16. A jack 17 of the scissors type supports plate 16 so as to be vertically adjustable, providing for adjustment in the distance between the tip of the nozzle 20 and the screen 15. The screen, in this case, is an ordinary woven one of 18 by 18 mesh per inch and is made of 0.015 inch diameter stainless steel wire. The screen is not secured to metal plate 16 but is free to be moved manually in a horizontal plane in any direction. The metal plate 16 is provided with a vent hole 18 which is vertically aligned with the axis of the nozzle 20 so as to pass fluid which issues from the nozzle; a tray 19 is adapted to catch any fluid which falls through vent hole 18.

The following example will illustrate operation of this apparatus for treating a staple fiber batt. The wire screen carrier 15 of Figure 1 is first covered with a sheet of Kraft paper, which serves to prevent entanglement of the fibers with the screen. Alternatively, a fine mesh screen may be used to minimize entanglement of the fibers with the screen, while still permitting drainage of water through the screen. A loose batt 14 of randomly arrayed staple fibers is then laid on the Kraft paper. The jack 17 is adjusted vertically so as to position the upper face of the batt about 1 inch below the tip of nozzle 20. The batt is then exposed to the action of the high velocity

stream of water while simultaneously being passed horizontally along a straight line in one direction. A series of batts, ranging in thickness from 1/16 to 3 inches are processed in this manner, successive passes being made along lines parallel to the first pass. Some of the batts are also subjected to successive passes along lines at right angles to the first passes. In all instances, it is observed that along the lines of fluid treatment, the fibers of the batt are driven generally downward, thus tending to consolidate the batt; in addition, the fibers are entangled and intertwined with one another and, in general, are drawn into a discrete continuous line coincident with the central axis of the nozzle or fluid stream.

The nozzle shown in Figure 2a is adapted to be connected to pipe line 8 and consists of a body 21 having an axial bore 22 which is generally closed at the bottom end except for a pair of orifices 23, 24 which are coplanar with each other and with the axis of the bore 22 and are inclined toward each other, in the direction of the fluid flow, at an included angle A. This angle is about 20° to 25° and the orifices are 0.007" diameter. Fluid streams emerging from the orifices 23, 24 are continuous but tend to break up as the two streams impinge on each other. In the use of this type of nozzle, the sheet material is placed either above or at the point of intersection of the streams. If the streams are allowed to intersect too far above the sheet material, the columnar effect of the streams is destroyed and the desired fiber interentanglement is not obtained.

A variation of the nozzle of Figure 2a is shown in Figure 2b, in which a pair of 0.007" diameter orifices 23, 24 are disposed parallel to each other and coplanar with the bore 22.

The nozzle shown in Figure 2c is similar to that shown in Figure 2a, except that a single central orifice 24 is used; this orifice is coaxial with the bore 22. At a pressure of about 1,000 lb./sq. in., a single 0.007" diameter orifice will deliver about 9.4 lbs. of water per hour and at 2,000 lbs./sq. in., 16.7 lb./hr.

An alternative apparatus for the continuous treatment of fibrous sheets is shown in Figure 4. Water at normal tap pressure is supplied through valve 81 and pipe 82 to a high pressure hydraulic pump 83. The pump may be a double-acting, single plunger pump operated by air from line 84 (source not shown) through pressure regulating valve 85. Air is exhausted from the pump through line 86. Water at 2000 lbs./sq.in. is discharged from the pump through line 87. A hydraulic accumulator 88 is connected to the high pressure water line 87. The accumulator serves to even out pulsations and fluctuations in pressure from the pump 83. The accumulator is separated into two chambers 89 and 90 by a flexible diaphragm 91. Chamber 89 is filled with water at 2000 lbs./sq.in. and chamber 90 is filled with nitrogen at the same pressure. Nitrogen is supplied through pipe 92 and valve 93 from a nitrogen bottle 94 equipped with regulating valve 95. Nitrogen pressure can be released from the system through valve 96. Water at 2000 lbs./sq.in. is delivered through valve 97 and pipe 98 to manifold 99 supplying orifices 100. The fine streams of water 101 emerging from orifices 100 impinge on the material being treated 102, which is supported by conveyor screen 103.

The nozzle shown in Figure 3 can be used when intermittent flow is desired. It resembles a diesel-engine type of fuel injection nozzle. The body 21 has an axial bore 22 in which a close-fitting cylindrical plunger 30 is situated. The plunger has a conical tip 31 adapted to form a fluid-tight seal in a mating conical seat 32 at the lower part of the bore 30. Axial passage 33, of smaller diameter

than bore 22, opens downward from the conical seat. An annular space 34 is cut into the conical seat. A fluid supply passage 35 is drilled downward through body 21 along side of bore 22 to communicate with the annular space. Plunger 30 is urged downward against the conical seat at a pressure determined by adjusting a spring 36. When this pressure is exceeded by fluid supplied to space 34 through passage 35, then plunger 30 is forced upward and a fluid passes downward through axial passage 33. A nozzle tip 37 screws onto the lower end of body 21 and is provided with orifices, such as orifices 24, 25, 26, which direct fluid from passage 33 downward in columnar flow. Any of the orifice arrangements shown in Figures 2a-2c can be used. Another suitable tip is provided with a central orifice 0.50 mm. in diameter surrounded by six orifices 0.45 mm. in diameter and equally spaced on a 50° included angle cone in the manner illustrated for orifices 24, 25 and 26.

When the nozzle of Figure 3 is used in the apparatus of Figure 1, intermittent impulses of high pressure fluid are supplied by an intensifier 40, a standard piece of equipment which, when supplied with driving air at a pressure of 40 psig., will boost the water pressure to about 20,000 pounds per square inch gauge in short pulses having a frequency of about one pulse per second. This is supplied to nozzle 20 through line 41 provided with a throttling valve 42. Water and air are supplied to the intensifier through lines 43 and 44, respectively. The hydraulic accumulator system described previously is not used when the intensifier is used, so line 8 is disconnected. The fibrous sheet material is treated in the same manner as before but the pulses of high velocity fluid, formed with the intensifier and nozzle of Figure 3, pierce the sheet material at intervals along the path of traverse under the nozzle.

Short discrete seam-like bonds and/or point seams are produced at each spot pierced by the intermittent stream. The frequency and duration of the fluid pulses may be controlled by adjusting spring 36, by throttling with valve 42, and by selection of the nozzle tip 37, to produce streams in the range of 0.0005 to 0.005 inch in diameter which impinge on the fabric at pressures of the order of 3000 pounds per square inch in the desired bonding pattern.

Instead of using individual nozzles and subjecting the fibrous sheet to a number of successive passes, a plurality of nozzles arranged in a row and spaced any desired distance apart may be used to increase the area of treatment in a single pass. By this method, parallel "seams" as close to each other as 0.025" or less can be produced in batt materials in two directions, changing their appearance to that of a woven fabric. Apparatus for the continuous production of a non-woven fabric by this process is shown schematically in Figure 5.

In the apparatus, a horizontal, belt-type screen conveyor 50 is adapted to transport a batt of fibers 28 in the direction of the arrow. Transverse of the conveyor is a plurality of spaced stationary nozzles 51 which are adapted to modify the batt along lines disposed in the direction of batt travel as denoted by the lines 52. Downstream of the nozzles 51 are one or more nozzles 53 which are arranged to be reciprocated transversely of the batt (by a mechanism not shown) so as to modify the batt along the lines 54 which are generally perpendicular to the lines 52. Still further downstream is a series of rollers 55a, b, c, and d which change the direction of the modified batt, causing it to be momentarily immersed in a liquid filled tank 56 for shrinkage, dyeing, bleaching, etc. At the

extreme right is a windup 58 for receiving product. The roller 55-d may be used for pressing or wringing the modified batt, heat treating or drying it, embossing it, etc.

In operation, a batt of fibers 28 is advanced from left to right under the various nozzles where it is modified (either continuously or intermittently) in one or more directions; the batt then travels to the liquid bath where it is shrunk, being subsequently dried or partially dried, and, finally being wound on a suitable core.

Figure 6 is a schematic illustration of an apparatus for the high speed production of continuous chenille-type yarns. In the apparatus, a horizontal belt-type screen conveyor 60 is adapted to transport a batt of fibers 28 beneath a plurality of equally spaced nozzles 61, which latter are adapted to modify the batt of fibers so as to form a plurality of separate chenille-type yarns. Downstream of the conveyor is a plurality of spaced circular cutting knives 62 arranged on a horizontal shaft and driven by a source of power not shown. At the extreme right is a plurality of windups including a suitable traversing mechanism (not shown) which windups form conventional cakes 63. In operation, the batt is advanced from left to right under the various nozzles where it is modified into discrete yarns equal in number to the number of nozzles; further downstream, the rotating knives 62 slit the yarns from neighboring ones and, finally, the yarns are individually wound to cakes 63.

In general, a variety of processes to obtain different products are possible according to this invention. How ver, a c mmon denominator among the many processes is the behavior of individual filaments or staple fibers under

the influence of high velocity fluid streams. The mechanism of the process appears to be one in which the fibers of the sheet material are caused to move, intertwine, or interlace with other fibers. The behavior of the fibers is best described with reference to Figure 7. Figure 7a shows a cross-section of a substantially unmodified batt of randomly arrayed fibers. It may be seen that carded and cross-lapped filaments are arrayed in strata in which individual filaments are more or less parallel to the horizontal; the filaments are not parallel to each other but are dispersed more or less randomly. The approximate boundaries of the strata are defined by horizontal lines; these lines are not intended to depict staple fibers. The behavior of one filament 70, marked with X's along its length, is reviewed below.

In Figure 7a, the filament 70 is seen to lie in the unmodified batt near the top of the batt and generally parallel to the plane of the batt.

Figure 7b shows the same batt after a short duration exposure to a high velocity fluid stream 38. In Figure 7b, the filament 70 is seen to be driven substantially through the entire thickness of the batt at two points 71 and 72. The high velocity fluid streams penetrate the full thickness of the batt and impinge upon the backing. The primary function of the backing is to serve as a support for the batt material. Preferably screen or similar material, which will permit the flow of water therethrough, is used. As it impinges on the backing, the stream or a portion thereof may be deflected, i.e., proceed in a generally horizontal direction or in the plane of the batt, carrying filaments therewith as shown by the loop in the filament at point 73. At this stage, the filament 70 is rather

thoroughly entangled with its neighbors and vice versa. In effect, the various strata of the batt are "sewn" or "stitched" together upon the migration and interentangling of the fibers.

Figure 7c shows the same batt after it has been manually turned over and treated with high velocity fluid streams on its reverse side. It is seen that further inter-entanglement and intertwining of the filaments occurs in random fashion so that the batt becomes highly coherent in the region in which it is treated by the fluid streams. Examination of the treated batt reveals that some filaments essentially pierce the batt at several different locations, thus acting as randomly dispersed sewing threads. The treated batt generally exhibits considerable tensile strength on a three-dimensional scale and also shows a markedly increased resistance to surface abrasion.

While the description just given does not specify the area of the batt that was treated, obviously any area up to and including the total area may be treated depending on the type of end product desired. For example, to obtain a quilt-like structure a batt would be treated along lines or "points" corresponding to the pattern of "seams" desired. A non-woven fabric may be obtained by treating a batt or layered structure over its entire area in one or more directions. The various types of products which may be obtained according to this invention are illustrated in the following examples.

EXAMPLE I

This example illustrates th conversion f a staple fiber batt into a quilt-like structure. A card d, cross-lapped batt of polyethylene terephthalat stapl fibers,

having a denier of 1.5 and a length of 1.5 inch, is laid on a sheet of Kraft paper on the wire screen carrier of the apparatus shown in Figure 1. The apparatus is equipped with the nozzle of Figure 2a. Using the continuous accumulator system and a pressure of 1,200 pounds per square inch, the batt is subjected to a high velocity stream of room temperature water by passing the batt horizontally under the nozzle at 50 to 60 yards per minute at a distance of about 1 inch below the tip of the nozzle. This distance corresponds approximately to the point of intersection of the two streams emerging from nozzle 2a.

Successive passes are made along lines parallel to the first pass and approximately 3/4" apart. In addition, a series of passes are then made, approximately 3/4" apart, along lines substantially at right angles to the first series of passes. The batt is then removed, dried, and examined. It now has the appearance of a quilted structure, having seams spaced about 3/4" apart in two directions. Figure 8 shows a 2X enlargement of a typical batt processed in this manner. The treated batt is now a coherent structure with substantial strength in all directions. The high degree of fiber interentanglement along the processed sections is readily observed. These sections take on the appearance of discrete seams as if separate threads have been embedded in the batt in the treated areas.

EXAMPLE II

This example illustrates the preparation of a quilted batt followed by shrinking to effect additional consolidation.

A batt composed of shrinkable polyethylene terephthalate staple fibers is processed in the same manner

as in Example I. The quilted structure, thus obtained, is then caused to shrink by passing it under jets of saturated steam at 50 pounds per square inch. In this manner, a fabric of relatively high strength is obtained from a normally weak, randomly-arrayed batt material. The appearance of a typical batt before and after shrinking is shown in Figure 9 at 2X enlargement.

EXAMPLE III

This example illustrates the preparation of a chenille-type yarn by the process of this invention. Using the conditions of Example I, a carded cross-lapped batt of polyethylene terephthalate staple fibers is subjected to the action of high speed fluid streams in a series of lines in one direction of the batt. Thus, in effect, a series of parallel seams is produced in the batt. Each of these seams is now cut from the batt to produce a yarn. By regulating the spacing between seams within the batt, it is possible to produce yarns of any desired bulk and texture. One characteristic of such yarns is that the fiber ends, produced when the seam is cut from the batt, protrude essentially normal to and 360° about the yarn axis. If made of a shrinkable fiber, the yarn may be subsequently subjected to a shrinking treatment to produce a yarn having the characteristics of a felt.

An advantage of this process is the high speed, economical production of a yarn directly from a bulk fibrous material. Another advantage is that the process may be used to produce yarns from fibers which cannot be processed into yarns by conventional yarn spinning techniques. Fine metal fibers may even be converted to yarns by the process of this invention.

Figure 10 shows typical chenille-like yarns of about 9000 denier produced directly from polyethylene terephthalate staple. The size of the yarn produced can be controlled by regulating the size of the "seam" and the distance from the seam axis along which the batt is cut. Other variations are possible depending on the length, denier, and type of staple fiber used. Additional effects can be obtained by varying the angle of contact of the fluid stream with the batt. Referring to Figure 10, the yarn sample on the right illustrates this effect. Thus in this sample, the filaments protrude at an angle with respect to the yarn axis. This effect is obtained by angling the fluid streams in the direction of movement of the batt during processing. In contrast, the other illustrated yarns are produced by directing the fluid streams normal to the batt during processing.

The production of yarn by this invention is not limited to staple fiber batts. Thus, continuous filament batts or composites thereof with staple fiber batts may be used to produce additional novel yarns.

EXAMPLE IV

This example illustrates the production of a non-woven fabric from a continuous filament web.

A loose web consisting of polyethylene terephthalate filaments randomly disposed throughout the web is treated in the following manner. The web is laid on a sheet of Kraft paper and placed on the wire screen carrier 15 of the apparatus of Figure 1. The continuous accumulator system is used in association with the nozzle of Figure 2b, to produce two parallel closely-spaced streams of room-temperature water. The jack is adjusted to bring the web to a position about 1 inch below the tip of the nozzle. The web is then moved horizontally in one direction at a rate of about 50-60 yards per minute. The process is repeated until a number of successive passes parallel to the first and substantially covering the entire area of the web are made. The web is then removed, dried and examined. The filaments of the web are observed to be so thoroughly interentangled with one another that the resulting structure has the coherence, strength and stability of a woven fabric. Individual layers of the filament batt cannot now be separated except by tearing the filaments.

EXAMPLE V

This example illustrates the treatment of a calendered web of continuous polyethylene terephthalate filaments, which are randomly deposed in the web and bonded at their crossover points. The web has a density of about 3 ounces per square yard.

The above described web is laid on a sheet of Kraft paper on the wire screen carrier of the apparatus shown in Figure 1. The apparatus is equipped with the nozzle shown in Figure 2b and the continuous accumulator system is used to produce two parallel, high velocity streams

of water. The web is then subjected to fluid action at 1500 pounds per square inch, while simultaneously being moved horizontally under the nozzle approximately 1 inch below the nozzle tip, at a rate of about 50-60 yards per minute. The process is repeated until a number of successive passes, parallel to the first, are made.

The web is then removed, dried and examined. Although the untreated web contained numerous bond sites, many of the filaments were free to move and did so. In the treated web, the filaments are observed to be interentangled with one another, thereby making the web highly coherent. The thickness of the web is not appreciably changed by the treatment. In general, the treated web has markedly improved three-dimensional strength and resistance to surface abrasion.

EXAMPLE VI

This example illustrates the use of high velocity fluid streams to attach a fibrous batt to a fabric.

A loose batt of polyethylene terephthalate staple fibers is laid on a 110 x 76, 70 denier, 34 filament nylon fabric. The composite is then laid on the wire screen carrier of the apparatus of Figure 1. The continuous accumulator system, at a pressure of 1200 pounds per square inch, is used in association with the nozzle of Figure 2c, the orifice of which has a diameter of 0.005 inch. The jack is adjusted to bring the upper face of the batt to a position approximately 1 inch below the tip of the nozzle. The composite is then passed horizontally in one direction at a rate of about 50-60 yards per minute. The process is repeated in successive passes first in one direction and then

transverse thereto. The composite is then removed from the screen carrier, dried, and examined. It is observed that the staple fibers have been forced by the high velocity fluid into and about the fabric, locking themselves by frictional restraint to other fibers and to the backing. By the use of the angled nozzle of Figure 2a, the degree of interentanglement and interlocking on the reverse side of the fabric can be increased.

Figure 11 shows a typical staple fiber batt stitched to a nylon fabric. At the left of the figure, a portion of the batt has been forcibly ripped away to give some idea of the degree of attachment.

EXAMPLE VII

This example illustrates the use of high velocity fluid streams to attach a continuous filament web to a fabric substrate.

A web composed of polyethylene terephthalate continuous filaments, disposed in random fashion throughout the web, is laid on the nylon fabric described in Example VI. The composite is then subjected to the action of high velocity fluid streams in the same manner described in Example VI. Again, it is observed that the filaments have been driven into and attached to the fabric. Figure 12 shows a 1-1/2 X enlargement of a single line of treatment as viewed from the reverse side of the fabric to show the attachment and interlocking of the filament web to the fabric.

In addition to attaching bulk fibrous materials to a fabric, the process of this invention may be used to attach staple and/or continuous filaments to virtually any

substrate, for example, to paper, sponge, cellular structures, wire screens, soft woods, metal and the like, without the use of needles, adhesives, thread, conventional sewing machines, staples, or other fasteners.

This example also illustrates the use of this process to produce a pile or fur-like effect. Thus, as shown in Figure 12, the reverse, or untreated side of the batt-fabric composite, consists of a series of protruding fibers. By proper control of processing conditions, a uniform pile-like surface may be obtained; if desired, the protruding fibers may be sheared to any desired pile height. The fluid streams may be caused to act on the fibrous material in any desired pattern and/or at different velocities to produce different effects. Natural and/or synthetic fibers, having a variety of lengths, crimp, color, texture and the like may be used to impart special effects.

EXAMPLE VIII

This example illustrates the use of pulsating flow to obtain "point seams" in a fibrous batt.

A batt, of approximately 1/4" thickness and consisting of carded and cross-lapped layers of 3" polyethylene terephthalate staple, possessing a minimum of cohesiveness normal to the plane of the batt and minimal shear and tensile strength in the transverse directions, is placed on Kraft paper on the wire screen carrier of the apparatus of Figure 1. The nozzle of Figure 3 is used in association with the intensifier 40 shown in the dotted system of Figure 1. The jack is adjusted so that the top face of the batt is about 1 inch below the nozzle 20. Using a fluid pressure at the n zzle tip of 1500 lbs./sq.in., the batt is

exposed to the action of short columnar streams of water, which strike the batt at intervals as it is traversed horizontally under the nozzle at a rate of about 30 to 60 yards per minute. The batt is then manually turned over and treated from its reverse side. The batt now contains small discrete areas of high fiber entanglement or "point seams" dispersed over its entire area. The discrete layers of the initial batt have substantially disappeared and portions of the batt can no longer be separated from each other except by tearing the fibers. The over-all cohesion and tensile strength is many times that of the untreated batt. An increased resistance to surface abrasion is also observed.

Various degrees of interentanglement can be obtained by regulating the velocity of the fluid stream and/or the distance between the batt and the tip of the nozzle. Thus, by increasing the velocity and/or positioning the batt closer to the nozzle tip, very dense areas of fiber entanglement having the appearance of nubs are produced within the batt.

EXAMPLE IX

This example illustrates the production of point seams in a cotton batt.

A sheet of cotton batting is processed as in Example VIII with the following exceptions. A nozzle of the type shown in Figure 3, but with a single central orifice of 0.5 mm diameter is used together with the intensifier system of Figure 1 and adjusted to give discrete fluid pulses at a rate of 10 to 15 per second at fluid pressures at the nozzle tip of 3,000 lbs./sq.in. At the location of each penetration of fluid into this batt of cotton, a

"point seam" is found well within the batt, which "point seam" is made up of surrounding and surface filaments.

Such processing thus provides a method for attaching layers of batt-like materials together, as in the above example, or for attaching batt materials to fabrics, cellular type backing, etc., at discrete points up to and including the entire area of the sheet material.

In the following examples, the tensile properties are measured on an Instron tester at 70°F. and 65% relative humidity. Strip tensile strength is determined for a sample 1/2 inch wide, using a two-inch sample length and elongating at 50% per minute. Grab tensile strength is measured on a sample four inches wide, using a three-inch sample length and elongating at 400% per minute. Initial modulus is determined by measuring the initial slope of the stress-strain curve.

The 5% secant modulus is determined by A.S.T.M. Standards E6-61, part 10, page 1836.

Drape flex is measured using a one inch by six inches sample and moving it slowly in a direction parallel to its long dimension so that its end projects from the edge of a horizontal surface. The length of overhang is measured when the tip of the sample is depressed under its own weight to the point where the line joining the tip to the edge of the platform makes an angle of 41.5° with the horizontal. One half of this length is the bending length of the specimen, reported in centimeters.

EXAMPLE X

This example illustrates the conversion of a layered c mposite into a non-woven fabric having the strength, drape and aesthetic properties of a conventional fabric.

(A) Forty denier, 27 filament polyethylene terephthalate continuous filament yarn is wound at 80 ends/inch in both directions around a metal frame, so that the yarns of one warp cross those of the other warp at a 90° angle. The yarns are then sprayed with a dilute (6%) water solution of polyvinyl alcohol and allowed to dry. This holds the yarns in place and the resulting structure is cut from the metal frame to yield two crossed warp sheets at end counts of 80 x 80. One of these sheets is then placed on a 30 mesh screen and covered with a carded staple batt (approximately 0.3 oz./yd.^{2}) of 1.5 dpf, 1-1/2" polyethylene terephthalate staple. Utilizing apparatus of the type shown in Figure 4 , the layered composite is passed under 0.0028" diameter orifices on 0.025" centers supplied with water at 1500 lbs./sq. in. One pass is made in each direction of the crossed warp yarns with the orifices just contacting the surface of the staple batt. The structure is then lifted from the screen and turned over. A second carded staple batt of the same type is placed on top of the crossed warp structure and the three-layer composite is subjected to the action of high speed fluid streams again. The structure is then lifted from the screen and turned over, i.e., returned to its original position, and again subjected to the high speed streams. Finally, the structure is removed from the screen, blotted between paper towels and ironed dry at an iron setting of 200°C. The resulting structure is a strong, drapable non-woven fabric having the following properties:

Test Direction	Basis Weight (oz./yd.^{2})	Tenacity (lbs./in./oz./yd.^{2})	Elong. (%)	Modulus (lbs./in./oz./yd.^{2})	Drape Flex (cm)
Warp	2.9	14.8	51	118	2.7
Bias	-	2.0	105	0.6	-

(B) Continuous filament webs can also be united with a crossed-warp by a similar procedure to produce a non-woven fabric having highly attractive properties, especially as to drape, conformability and abrasion resistance. A crossed-warp structure is made from 70 denier, 34 filament polyethylene terephthalate yarn at 40 ends per inch. The structure is sprayed with a polyvinyl alcohol size to permit bonding in subsequent operations. On each side of the crossed-warp structure there is placed a continuous filament web, having a basis weight of approximately 1.0 oz./yd.^{2}, and consisting of two-component, post-crimpable filaments prepared from polyhexamethylene adipamide and a copolymer of polyhexamethylene adipamide and polyhexamethylene sebacamide.

Using apparatus of the type shown in Figure 4, the composite is subjected to high velocity fluid streams using 1500 lbs./sq.in. pressure and a 30-mesh backing screen in the following sequence:

1st: 2 passes on each side using 0.0028" orifices
2nd: 2 passes on each side using 0.005" orifices
3rd: 2 passes on each side using 0.007" orifices

The structure is then removed and dried. Crimp is developed by subjecting it to 30 lbs./sq. in. gauge saturated steam for about 1 minute in an autoclave. The resulting non-woven fabric has a basis weight of about 6 oz./yd.^{2} and a good balance of tensile strength, compliance, bending length and abrasion resistance as shown in the table below. Abrasion resistance is determined as described in ASTM Standards (1961), Part 9, pages 318-326, except that the flat sample-holding plate is replaced by a curved plate, having a radius of curvature of 6 inches at the surface over which the test sample is wrapped.

	Tenacity (lbs./in./oz./yd.^{2})	Elong. (%)	Mod. (5% Secant) (lbs./in./oz./yd.^{2})	Drape Flex (cm.)	Abrasion Resistance cycles to fail
Machine Direction	8.07	77	5.1	2.67	79
Bias Direction	4.38	171	0.53	2.64	70

The fact that continuous filaments can be so thoroughly interentangled with a crossed-warp as to produce a stable, coherent non-woven fabric, further emphasizes the high degree of fiber-interentanglement obtained by the process. This coherence is evident from the high abrasion resistance (70-79 cycles). Comparable structures, which have not been hydraulically treated, fail within 10 cycles.

EXAMPLE XI

This example illustrates the production of a non-woven fabric by interentangling staple fibers into a scrim base.

A carded stapled batt (approximately 0.4 oz./yd.^{2}) of 2 dpf, 1-1/2" polyacrylic staple is placed on top of a commercial cotton cheesecloth (24 x 24 construction), which in turn is laid on a 30-mesh screen. Using apparatus of the type disclosed in ~~Figure~~ 4, the composite structure is treated with water supplied at 1500 lbs./sq.in. to 0.0028" diameter orifices on 0.025" ~~centers. One pass is made in~~ each direction of the yarns in the cheesecloth with orifices just contacting the surface of the staple batt. The structure is then lifted from the screen and turned over. A second carded staple batt of the same type is placed on top of the cheesecloth and the treatment repeated. The structure is again lifted from the screen, turned over, and the treatment is repeated. The structure is then removed from the screen, blotted between paper towels and ironed dry. The following table lists properties of the original cheesecloth, the non-woven fabric made as described above with one carded batt of staple on each side and treated three times, and a similar structure made from two carded staple batts on each side and treated five times.

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	Basis Weight (oz./yd.^{2})	Warp Grab Tenacity (lbs.)	Warp Grab Elong. (%)	Bias Strip Tenacity (lbs./in./oz./yd.^{2})	Bias Strip Elong. (%)	Bias Strip M_s 5% (lbs./in./oz./yd.^{2})	Drape Flex (cm) W	Drape Flex (cm) B
Cheesecloth	0.96	11.8	8.0	0.31	20	0.10	2.1	1.8
Cheesecloth + 2 Batts	1.75	13.8	80	1.25	50	0.22	1.9	1.8
Cheesecloth + 4 Batts	2.33	18.8	91	1.85	66	0.30	2.0	1.8

EXAMPLE XII

This example illustrates the production of a non-woven fabric from a layered composite consisting of a continuous filament web with a staple fiber batt over- and underlay.

A carded staple batt (approximately 0.3 oz./yd.^{2}) of 1.5 dpf, 1-1/2" polyethylene terephthalate staple fiber is placed on a loose web consisting of polyethylene terephthalate filaments randomly disposed throughout the web. This structure is then placed on a 30-mesh screen and, using apparatus of the type showing in Figure 4, is treated with water supplied at 1500 psi to 0.0028" diameter orifices on 0.025" centers. Two passes are made under the orifices, the second pass being at 90° to the first pass, with the orifices just contacting the surface of the staple batt. The structure is then lifted from the screen, turned over, and the process repeated with another staple batt on top of the web. The structure is then returned to the original position and again subjected to the high speed streams of water. The following table lists properties of the untreated web, the non-woven fabric made as described above with one carded batt of staple on each side and treated three times, and a similar structure made with two carded batts on each side of a continuous filament web and treated five times.

	Basis Weight (oz./yd.^{2})	Tenacity (lbs./in./oz./yd.^{2})	Elong. (%)	Modulus (lbs./in./oz./yd.^{2})	Drape Flex (cm.)
Continuous Filament Web	1.44	0.33	12	5.9	2.4
Continuous Filament + 2 Batts	2.00	0.90	86	0.8	2.3
Continuous Filament Web + 4 Batts	2.57	3.12	145	2.7	2.8

EXAMPLE XIII

This example illustrates the preparation of a drapable nonwoven fabric combining conformability and elasticity without bulk.

Seventy denier spandex elastic yarn is wound into a cross-warp at 50 ends/inch each way over 30-mesh screens. The cross-warp is self-bonded by a 30-second treatment between 30-mesh screens in a press at 215°C., 330 psi for 30 seconds.

The cross-warp is then removed from the screen and hydraulic-treated as follows in a manner similar to Example X:

1. 0.1 oz./yd.^{2} polyethylene terephthalate carded batt is hydraulically attached to one side with 3 mil jet 1500 psig over 30-mesh screen. Two passes on each side against the face of the jet are made.

2. A second polyethylene terephthalate batt is hydraulically attached to the other side with 3 passes alternating sides using same conditions as in 1.

3. Sample is dried and pressed flat at 100°C., 200 psi for 30 seconds. A light weight, drapable, nonwoven fabric of woven fabric aesthetics is obtained.

Properties

Wt. (oz./yd.^{2})	2.1
Th. (mils)	9
T (lb./in./oz./yd.^{2})	0.9
E (%)	274
$M_{5\%}$ sec. (lb./in./oz./yd.^{2})	0.4
BL (cm)	1.4
TR_5/TR_{10} (%)	87/84
WR_5/WR_{10} (%)	71/63

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EXAMPLE XIV

This example illustrates the production of a non-woven fabric from a loose fibrous web.

A loose web consisting of polypropylene continuous filaments randomly disposed throughout the web is treated in the following manner. The web is laid on a 30-mesh screen and, using apparatus of the type shown in Figure 4, is passed under a series of 0.0028" diameter orifices on 0.025" centers supplied with water at 1500 lbs./sq.in. Two passes are made under the orifices, the second pass being at 90° to the first pass, with the orifices just contacting the surface of the web. The structure is then lifted from the screen, turned over and treated again. A coherent, stable non-woven fabric is thus obtained from the loose web. The high degree of fiber interentanglement produced by the action of the high speed streams of water is evident from the increased strength of the treated web. Properties of the treated and untreated webs are given in the table below:

	Basis Weight (oz./yd.^{2})	Tenacity (lbs./in./ oz./yd.^{2})	Elong. (%)	Modulus (lbs./in/ oz./yd.^{2})	Drape Flex (cm.)
Untreated	1.5	0.13	53	0.2	2.1
Treated	1.6	1.0	152	0.8	1.9

EXAMPLE XV

This example illustrates the use of high speed liquid streams to develop surface cover on woven fabrics and to produce a fulling and napping effect.

A suiting fabric is supported on a 20-mesh screen and, using apparatus of the type shown in Figure 4, is subjected to streams of 1500 lbs./sq.in. water, emerging from

0.007-inch diameter orifices on 0.050-inch centers. The fabric is subjected to four passes in the bias direction at the orifice faces. The treated fabric has the appearance of having been fulled and/or napped and has an increased surface cover. These effects are found in a variety of fabric types including worsted, woolen spun, and flannel fabrics composed of wool/synthetic fiber blends. Typical properties of untreated and treated fabrics are given in the table below:

4 passes in bias direction one side only

NO SPEED SO CAN'T FIGURE ENERGY

	Tenacity (lbs./in./oz./yd.^{2})	Elong. (%)	Modulus (lbs./in./oz./yd.^{2})	Drape Flex (cm.)
Polyethylene terephthalate/wool worsted:				
Untreated	2.3	50	0.15	1.6
Treated	3.1	69	0.60	2.3
Polyacrylonitrile/wool flannel:				
Untreated	1.0	70	0.08	1.8
Treated	2.0	80	0.22	2.4

FABRIC GOT STIFF

EXAMPLE XVI

This example illustrates similar treatment of a knit fabric to improve its stability and to alter its surface character and tactile hand.

A sample of interlock sweater fabric made of polyacrylic fibers is treated with high velocity streams of water from 0.007" diameter orifices on 0.050" centers supplied with water at 1500 lbs./sq.in., using apparatus with the type shown in Figure 4. The fabric is supported on a 20-mesh screen and passed under the orifices at their faces. Two passes are made, the second being 90° to the first. The fabric is then turned over and treated again. A total of four such treatments (tw on each side) are made on the fabric. Properties of the treated and untreated fabric are as follows:

ELONGATION DECLINES

NO SPEED

	Untreated	Treated
Tenacity (lbs./in./oz./yd.^{2})		
Wale direction	2.86	3.08
Course direction	2.43	3.23
Elongation (%)		
Wale direction	145	144
Course direction	269	180
5% Secant Modulus (lbs./in./oz./yd.^{2})		
Wale direction	0.04	0.15
Course direction	0.03	0.11
Drape Flex (cm.)		
Wale direction	1.04	2.65
Course direction	.92	1.83

STIFFER CLOTH

In addition to the above changes in physical properties, the treated fabric also has a marked change in aesthetic properties. The fabric has a "cleaner" appearance, i.e., is relatively fuzz-free, and a firmer hand.

EXAMPLE XVII

This example further illustrates the use of high speed columnar streams of liquid to improve the covering power and uniformity of appearance of conventional fabrics.

A commercial shirting fabric made from a blend of cotton and polyethylene terephthalate fiber is subjected to the action of high velocity streams of water in the following manner. Using apparatus of the type shown in Figure 4, water is supplied at 1500 psi to 0.007" diameter orifices on 0.050" centers. The fabric is supported by a 30-mesh screen and is passed under the orifices three times, the fabric being in contact with the faces of the orifices. The fabric is passed under the orifices such that the streams traverse the fabric in the bias direction of the fabric. The fabric is then lifted from the screen, turned over, and treated again in a bias direction but at an angle of 90° to the first treatment. The streaks and non-

uniformity in the original fabric are removed and, in addition, the treated fabric is observed to have an improved covering power as shown by the data below:

	Untreated	Treated
Transmitted light	5.0%	3.9%
Reflected light	78.5%	80.3%

The above data on reflected light is determined with a photoelectric reflection meter (Model 610, Photovolt Corp.) from the reflectance of the fabric against a white background of known reflectance and against a black background of known reflectance. The data on light transmitted is determined with a photoelectric cell for light transmitted through the fabric from a diffuse light source (Durst No. 609 Projector).

Similar treatment of other types of fabrics also produces improved covering power as illustrated below:

WHAT CONDITIONS?

	Untreated		Treated	
	Reflected Light	Transmitted light	Reflected light	Transmitted light
Nylon Tricot	66.2%	21.4%	71.6%	14.3%
Nylon Taffeta	66.8%	10.2%	76.0%	4.9%

In another experiment, a continuous running length of fabric is treated in the same manner as described above except that the liquid discharge pipe is placed at an oblique ~~angle with respect to~~ the direction of travel of the fabric and the pipe is also angled so that the streams of water flow at an angle toward the oncoming fabric. This treatment produces the same effect as if the fabric were treated on the bias, thus providing a suitable method for continuous treatment of long lengths of fabric.

EXAMPLE XVIII

This example illustrates the production of a non-woven fabric from a staple fiber batt.

A loose batt consisting of carded polyethylene terephthalate staple fibers (1.5 dpf, 1.5 inches) is used as the starting material. One sample, designated "A", of the batt is placed on a 30-mesh screen and, using apparatus of the type shown in Figure 4, is subjected to the action of high velocity water supplied to 0.0028" orifices on 0.025 inch centers at 1500 lbs./sq.in. The batt is passed so as to just contact the orifices. Two passes are used, one transverse to the other, on each side of the batt, i.e., the batt is subjected to a total of 4 passes. The batt is then removed, dried and examined. It is now a stable, coherent non-woven fabric. A second sample, designated "B" consisting of 2 layers of the above carded staple batt, is then converted to a non-woven fabric as above except that 4 passes are used per side, each successive pass being transverse to the one preceding it, to give a total of 8 passes. In the table below properties of the untreated and both treated samples are given. In the table, "M.D." refers to the machine direction of the batt and corresponds to the direction in which most fibers are aligned; "T.D." refers to the transverse direction.

Sample	Tenacity (lbs./in./oz./yd.^{2})		Elong. (%)		Modulus (lbs./in./oz./yd.^{2})	
	M.D.	T.D.	M.D.	T.D.	M.D.	T.D.
Untreated	0.02	0.004	54	68	0.04	0.008
Sample "A"	11.10	1.730	81	134	1.90	0.470
Sample "B"	15.50	3.100	74	110	2.10	1.100

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EXAMPLE XIX

In operating the process of this invention, velocity and consequently momentum of the discrete column of fluid contacting the fibers must be sufficiently high as to physically drive the fibers into an interentangled relationship with other fibers. The actual velocity required is dependent on the nature of the fibrous sheet to be treated and on the degree of fiber interentanglement desired. Velocity may be adjusted to any desired level, for example, by varying the pressure on the liquid in Figure 1 or the output of the pump in Figure 4 and/or by varying the size of the nozzle orifice. In the following table, the effect of varying the pressure and/or the orifice size is shown. In each case, the starting material is a continuous filament web. The web is placed on a 30-mesh screen and treated using apparatus of the type shown in Figure 4. The web is subjected to two passes, one transverse to the other, on each side of the web and is passed so as to just contact the orifices.

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	Orifice (in.)	Pressure (lbs./in.^{2})	Velocity (ft./sec.)	Momentum Per Unit Area (lb.-ft./sec./ ft.^{2} x 10^{-5})	Tenacity (lbs./in./ oz./yd.^{2})	Elong. (%)	Modulus (lbs./in./ oz./yd.^{2})	Drape Flex (cm.)
(a)	0.0028	2000	258	41.7	3.42	156	1.00	2.2
(b)	0.0028	1000	105	6.7	0.53	87	0.40	1.9
(c)	0.0028	500	54	6.2	0.21	56	0.12	1.7
(d)	0.005	2000	---	--	4.55	151	0.76	2.1
(e)	0.005	1000	144	12.7	2.17	110	0.88	1.5
(f)	0.005	500	110	7.6	1.79	138	0.36	2.1
(g)	0.007	2000	278	47.4	3.68	168	0.93	2.2
(h)	0.007	1000	156	15.2	3.72	143	0.53	1.7
(i)	0.007	500	112	7.9	1.05	91	0.34	1.8
Properties of untreated web for comparison					0.14	53	0.07	1.6

	Orifice (in.)	Pressure (lbs./in.^{2})	Distance from Orifice (in.)	Tenacity (lbs./in./oz./yd.^{2})	Elong. (%)	Modulus (lbs./in./oz./yd.^{2})	Drape Flex (cm.)
(a)	0.0028	2000	contact	3.42	156	1.00	2.2
~~(b)~~	~~0.0028~~	~~2000~~	~~1~~	~~3.46~~	~~118~~	~~0.54~~	~~1.9~~
(c)	0.0028	2000	2	2.60	122	0.58	2.1
(d)	0.0028	2000	4	Turbulence destroyed sample			
(e)	0.0028	1000	contact	0.53	87	0.40	1.9
(f)	0.0028	1000	1	0.65	90	0.24	1.9
(g)	0.0028	1000	2	0.55	87	0.20	---
(h)	0.0028	1000	4	0.17	67	0.18	---
(i)	0.007	2000	contact	3.68	168	0.93	2.2
(j)	0.007	2000	1	1.31	123	0.27	1.5
(k)	0.007	2000	2	Turbulence destroyed sample			
(l)	0.007	2000	4	Turbulence destroyed sample			
(m)	0.007	1000	8	0.18	78	0.08	2.1

Using tenacity as an indication of the extent of fiber interentanglement, it is observed from the above table that the extent of fiber interentanglement generally decreases as the distance from the nozzle orifice increases. For larger orifices and/or higher pressures, turbulence tends to limit the maximum distance. For lower pressures, the samples may be treated at greater distances without being destroyed by turbulence. However, all other factors being equal, the extent of fiber interentanglement decreases as the pressure decreases.

EXAMPLE XXI

The extent of fiber interentanglement obtainable at any given pressure can be increased by increasing the number of passes. The following table illustrates the effect of repeated passes on a continuous filament web. Apparatus of the type shown in Figure 4 is used. The sample is placed on a 30-mesh screen and is passed so as to just contact the 0.0028" orifices supplied with water at 1500 lbs./in.^{2}. Each treatment consists of two passes, one transverse to the other, per side of the web.

Treatments (sides)	Tenacity (lbs./in./oz./yd.^{2})	Elong. (%)	Modulus (lbs./in./oz./yd.^{2})	Drape Flex (cm)
1	0.54	93	0.17	1.7
2	5.15	129	1.45	1.6
4	3.30	142	0.36	1.8

reaches loss of strength after 2 passes on each side

Nozzle orifice size may also be varied depending on the material to be treated and the effect desired. In general, for treating loose fibrous batts and the like, it is preferred to vary the orifice size according to the basis weight of the sheet and the denier of the fibers therein. Preferably, small diameter orifices

(e.g., 0.0028") are used for low basis weight, low denier materials, while larger orifices (e.g., 0.005" or 0.007") are used as the basis weight or denier increases. For more structurally stable starting materials, such as woven or knitted fabrics, it is preferred to use larger diameter orifices (e.g., 0.007") to obtain a high degree of fiber interentanglement.

As can be seen from the foregoing discussion and the examples, the process of this invention offers a high speed economical route to the production of a wide variety of textile products. In order to obtain the high degree of fiber interentanglement which characterizes the products of this invention, the starting material is acted upon by discrete columnar streams of a non-compressible fluid moving at high velocity.

The fluid must be non-compressible, i.e., a liquid, since the stream must be capable of maintaining its identity as a discrete column for a finite distance beyond its point of emergence from the nozzle orifice. Compressible fluids, such as air, nitrogen, or other gases, which diffuse rapidly upon emerging from a nozzle orifice, are not effective. The results obtained by treatment with water and nitrogen are compared in the following example.

EXAMPLE XXII

A loose web consisting of randomly disposed continuous filaments is used as the starting material. Using apparatus of the type shown in Figure 4, a sample of the web is placed on a 30-mesh screen and passed in contact with 0.0028" orifices n 0.025" centers supplied with water at 2000 lbs./sq.in. pressure. Two passes are used, one transverse t the ther, on each side of the

40g

web. The web is removed, dried and examined. The loose web is observed to have been converted into a stable coherent non-woven fabric. A second sample is similarly treated except that 0.007" orifices on 0.050" centers are used and the sample is placed on a 10-mesh screen. Properties of the untreated and treated webs are given in the following table:

	Tenacity (lbs./in./ oz./yd.^{2})	Elong. (%)	Modulus (lbs./in./ oz./yd.^{2})	Drape Flex (cm)
Untreated web	0.14	53	0.07	1.6
0.0028" orifice	3.42	156	1.00	2.2
0.007" orifice	3.68	168	0.93	2.2

The marked increase in tensile strength of the water-treated samples shows that a high degree of fiber interentanglement has occurred.

The above two experiments are then repeated on additional samples of the web under identical conditions except that nitrogen at 2000 lbs./sq.in. is used instead of water. The nitrogen-treated samples are removed and examined. A few surface fibers appear to have been blown around but no other visible effect is noted. The strength of these samples is substantially unchanged from that of the untreated web.

The above experiments are then repeated using a staple fiber batt as the starting material. Again, treatment with the high velocity liquid streams is observed to interentangle the fibers whereas treatment with the gaseous streams has no effect.

In a final test in this series, a sample of the staple batt is first moistened with water and then subjected to the action of nitrogen from 0.007" orifices at 2000 lbs./sq.in. No fiber interentanglement is observed.

Since many different embodiments of the invention may be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited by the specific illustrations except to the extent defined in the following claims.

SUPPLEMENTARY DISCLOSURE

It has now been found that certain preferred products may be prepared by preferred process embodiments.

The preferred process for preparing the preferred fibrous sheet material of this invention is characterized in that:

(a) Fibers or filaments in the fibrous web are moved relative to each other by the impingement force of a fine columnar stream of a noncompressible fluid, issuing from an orifice onto the web;

(b) The momentum-flux of the fluid is at least 6 kg-m/sec^2-cm^2 at the point of impingement onto the web;

(c) The web and fluid orifice move relative to each other if desired.

Preferably the fluid has an orifice velocity of at least 6000 cm/sec.

2.4 cm = 1"

$\frac{6000}{(2.4)(12)}$ = Ft/min

Preferably, the fibers in the fibrous web have the latent ability to shrink, crimp or elongate and a subsequent treatment comprises heating the filaments to cause, respectively, shrinkage, crimping or spontaneous elongation of the filaments.

In a highly preferred embodiment, the divergence angle of the fluid stream is less than 3°.

The fibrous web can be any sheet-like structure composed of textile filament in the form of staple fibers, continuous filaments, or yarns, and layered composites thereof. Blends

of fibers of different chemical type, length, denier and other properties may also be used. This web may be in a single layer or multiple layers and may include a scrim or reinforcing material which itself is not affected by the processing.

By "impingement force of a fluid" is meant both the force component of the fluid essentially normal to the plane of the web, and the lateral forces resulting from the projected stream striking a backing member. The fibers move in the web under this force, thus entangling with those fibers around them.

Orifice velocity means the average velocity across the cross section of the fluid stream at the orifice. This may be estimated from the fluid throughput assuming an orifice discharge coefficient of 0.62.

"Fine columnar stream" means a stream of small cross-sectional dimension, preferably less than .030 inches (.076 cm).

Momentum-flux is the force per unit area exerted by the fluid stream on the web at the web surface. Momentum-flux equals the impact force of the fluid stream divided by the effective area of the fluid stream at the web surface. The impact force of the fluid stream may be determined experimentally by placing a pan balance at a known distance below the orifice from which the stream emerges and measuring the force which just balances that of the stream. The measured impact-force is mathematically equivalent to the momentum-flow-rate of the stream at the plane of the balance, assuming that the collision between the fluid stream and the balance is inelastic. The momentum-flow-rate is the rate of momentum flow past a plane transverse to the fluid stream and can be calculated from the throughput of given liquid per given orifice in a given time interval.

Momentum-flux can then be determined by dividing the measured or calculated impact force by the effective area of the fluid stream where the stream impinges on the web. The area of
B the stream is most easily determined by measurements taken from

photographs of the stream.

"Columnar" means the streams have a total divergence angle of not greater than about 5°. Columnar streams minimize air turbulence at the surface of the web during processing.

"Fine columnar stream" means a stream of small cross-sectional dimension, preferably less than 0.030 inches (0.076 cm).

The high strength products of the present invention can be produced with columnar streamsexerting a momentum-flux of greater than about 6 kg-m/sec^2-cm^2. Such streams can be obtained by propelling a suitable, noncompressible fluid, such as water, at high pressures through small diameter orifices under conditions such that the emerging streams remain essentially columnar at least until they strike the initial material. Particularly strong and surface-stable fabrics are obtained with high-pressure fluid streams having an angle of divergence of less than about 3°. The use of columnar streams provides the further advantage of minimizing air turbulence at the surface of the web during processing.

If desired, the initial fibers or layer may be treated first with a wetting agent or other surface agent to increase the ease of processing, or such agents may be included in the fluid stream. Similarly, processibility of stiff fibers is enhanced by using hot fluid to lower fiber modulus during processing.

This process can operate on low weight webs ($\lesssim$ 5 oz/yd^2), ($\lesssim$ 170 gm/m^2) as well as webs of higher weight.

Depending upon the nature of the initial fibrous layer, the momentum-flux exerted by the fluid may be regulated by varying the size of the orifices from which the streams emerge, the pressure at which the noncompressible fluid is delivered, the distance the web is separated from the orifices, and/or the fluid itself. Other process variables, which may be manipulated in order to achieve the desired product, include the number of times the web is passed into the path of the streams, and/or the directi ns in which the web is passed into the path of the streams and

the topography of the supporting member. In general, webs having a weight ranging from 8.5 gm/m^2 or less to about 406 gm/m^2 or more and composed of natural, cellulosic, and/or wholly synthetic fibers, can be readily converted into the textile materials that are preferred embodiments of the present invention using water and process conditions within the following ranges:

Orifice size	0.0076 - 0.076 cm
Orifice spacing	0.025 - 0.25 cm
Water pressure	7 - 352 kg/cm^2
Web-to-orifice separation	0 - 15.2 cm
Number of passes	1 - 100

In a preferred continuous process, the web on a supporting member moves under multiple oscillating fluid jet streams. In this preferred process many regions of high fiber entanglement are produced. Many series of fluid streams may be used to process the web such that entangled regions formed by the action of a jet adjoin or overlap regions formed by the actions of other jets.

The ease with which a given web can be entangled is dependent upon many factors, and process conditions may be chosen accordingly. For example, webs of low density may be processed more easily than comparable webs of high density.

The higher the modulus and/or denier, the higher the impact pressure and greater the duration of treatment necessary to make the product. Because of their lower modulus, crimped fibers are preferred.

Similarly, the higher the weight or the thickness of the web, the greater the total force necessary to penetrate the web.

The web is supported during processing under the applied fluid force because typical initial starting material is not strong enough to hold together without support during initial processing.

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A backing member, if used, may be a perforated plate,

sheet, woven screen, honeycomb or the like, made of any suitable material which is not susceptible to attack by the fluid used in the process. Suitably, a fine mesh woven wire screen is used. This will usually be flat, but may be shaped in a three-dimensional contour. Choice of backing member depends in part on the weight of the web being treated. Low weight webs should be treated on backing members with low open area and small openings. For heavier webs, larger openings may be satiffactory.

The product of this invention is a nonforaminous non-woven fibrous sheet comprising fibers or filaments or mixtures thereof characterized by having fibers or filaments therein so entangled with other fibers or filaments that

(a) the impenetrability rating (I) of the highly entangled regions is at least 0.5 when the sheet is in the bond free state, and

(b) the entanglement frequency (f) is at least 20/inch (7.9/cm) when determined in the bond free state.

Preferably, the product is also characterized in that the entanglement completeness (C) is at least 0.7 when measured in the bond free state and, more preferably, also has a 45/90/135 number of at least 10.

In one embodiment the entangled regions are discrete areas and define a pattern.

Where the entangled regions are discrete areas, the structural measure of fiber entanglement in the regions of highest fiber entanglement and fiber cooperation in the structure, (S), is preferably at least 0.1 when the sheet is in the bond free state.

In a highly preferred embodiment, the fabric weight is not more than 170 gm/m^2, the 5% secant modulus in at least one direction is preferably less than 10.6 $gm/cm//gm/m^2$, the cantilever bending length in at least one dire tion is, preferably, less than 2.0 cm, the strip tensile strength in one direction is,

preferably, greater than 10.6 gm/cm//gm/m^2 and the tongue tear strength in at least one direction is, preferably, greater than 9.4 gm//gm/m^2 all measurements made in the absence of binder.

Coherent drapable products of a weight as low as 17 g/m^2 are a species of this invention.

A fibrous structure dependent on inter-fiber entanglement for strength and integrity may be characterized by:

(a) the inter-fiber friction in the areas of highest entanglement - a measure of entanglement;

(b) the number of times/unit length of fiber, a fiber segment is operative in regions of highest entanglement (the frequency of entanglement along a fiber length);

(c) the percentage of fibers in the regions of highest entanglement which are operative (bear stress under load) - the entanglement completeness;

(d) the out of plane character (transverse to the plane of the structure) of the fibers in the entangled regions, and

(e) - (for structures having discrete entangled areas) - the interaction between the completeness of entanglement and the cooperation of fibers between discrete entangled areas in bearing stress.

"I" is a measure of the inter-fiber friction in highly entangled areas and is thus a measure of entanglement. "I" is the ratio of the number of delineated highly entangled areas not penetrated by a given needle to the total tested.

The test comprises dropping a given needle under given conditions on delineated areas, which areas are representative of the structure of the highly entangled regions. The test is repeated until the experimenter has measured 25 delineated areas. The number of areas not penetrated by the needle divided by 25 is "I".

"f", the average ntanglement frequency, is defined as the geometric means of f_{d1} and f_{d2} where

$$f_{d1} = \frac{2(F_2 - F_1)}{w_1F_2 - w_2F_1} .$$

f_{d1} is the entanglement frequency measured in a chosen fabric direction and f_{d2} is the entanglement frequency measured at right angles to the chosen fabric direction d1.

F_1 is the tensile strength of a strip of specimen w_1 wide. F_2 is the tensile strength of a strip of the same specimen w_2 wide. w_1 is one-fifth w_2. w_2 usually should be 1 inch (2.54 cm) unless other factors interfere.

The test for (f) is described in more detail hereinafter.

"C", the entanglement completeness, is the proportion of fibers that break when a specimen is broken and is the geometric mean of C_{d1} and C_{d2} where C_{d1} is the completeness measured in a given direction and C_{d2} is the completeness measured at right angles to C_{d1}.

$$C_{d1} = \frac{F_d}{F_s}$$

where F_d is the tensile strength of a 1 inch (2.54 cm) wide specimen with a 1.5 inch (3.8 cm) gauge length (distance between clamps) and F_s is the tensile strength of a specimen of the same sample of the same width in the same direction with a 0.15 inch (0.38 cm) gauge length. The test is further described hereinafter.

The 45/90/135 number is a measure of fiber tranversity or out of plane character of the fibers in the structure. Specifically, sixty cross-sections of the fabric are scanned to find the region of greatest fiber transversity in each section. In each region the total fiber length at 90 ± 12° with respect to the fabric plane is compared with the total fiber length in that region at 45 ± 12° and 135 ± 12°. The number of sections for which this total fiber length at 90° ± 12° is greater than the total fiber length at both 45 ± 12° and 135 ± 12° is called the 45/90/135 number.

"S" is a measure of fiber entanglement and cooperation

and is defined by

$$S = \frac{\rho d}{L}$$

The fiber concentration factor (ρ) is the ratio of the weight per unit area of the entangled portion (W_1) to the weight per unit area of the entire fabric (W_2), i.e., $\rho = \frac{W_1}{W_2}$. For uniformly entangled products, $\rho = 1$.

The density of the region of highest entanglement is denoted (d).

"L", the average free length factor of fibers, is a measure of fiber cooperation under stress and is measured from fibers between entangled areas where such fiber exists.

The formula for S recognizes that the free-length factor is inversely related to strength conversion, i.e., the greater the free-length factor, the more chance for poor fiber cooperation.

The 5% secant modulus is the secant modulus at 5% elongation on the stress-strain strip tensile curve recorded at a crosshead speed of 1 inch/min (2.54 cm/min) and a gauge length of 2 inches (5.08 cm). Strip tensile strength is also measured according to the above method, using a 1/2 inch (1.27 cm) sample width.

Tongue tear strength is determined using 4 inch (10.16 cm) x 0.5 inch (1.27 cm) specimen, a gauge length of 1 inch (2.54 cm) and a crosshead speed of 10 inch/min (25.4 cm/min). A slit is made in the sample in the direction of testing and one side is mounted in one clamp and the other side in the opposed clamp. The force to tear is recorded.

Bending length is determined according to ASTM Test 1288-55T.

"Bond free state" means in the absence of any substantial inter-fiber coherence, other than that induced by fiber entanglement. For example, thes tests are run in the absence of

chemical binder or inter-fiber fusion bonds.

"In the absence of binder" means in the absence of any resinous chemical bonds, or bonds provided by a non-fibrous substance.

Sheet structures having an $I \geq 0.5$ and $(f) \geq 7.9$/cm are integral strong and surface stable in the absence of any external bonding and are thus unique nonwoven fabrics. These fabrics are suitable for textile use without further processing. Such structures which have $C \geq 0.7$ have additional strength and those with $45/90/135 \geq 10$ have superior surface stability. For structures with discrete area entanglement, an $S \geq 0.1$ in combination with proper values of $f \geq 7.9$/cm and $I \geq 0.5$ indicates a fabric-like structure having high integrity, strength and fabric-like break characteristics (catastrophic break rather than the tearing phenomena usually associated with nonwovens).

<u>Characterization Tests</u>

The I test rates a sample of the entangled area by needle impenetrability. The needle has a shank about 0.015 inch (0.038 cm) in diameter with a conical point having sides making an angle of about 26° with the axis. The needle is held by an L. S. Starret "C" pin vise, the total weight of the assembly being about 24 grams. This is used in conjunction with a support plate, 1/32 inch (0.078 cm) in thickness, having a series of holes of different diameters drilled in it. These holes are suitably marked for diameter-identification.

To obtain an impenetrability rating (I), a section of the fabric is marked so as to delineate a region containing 25 circular entangled areas. The average diameter of the entangled areas is estimated with a hand comparator and the specimen is placed on the above-mentioned plate, so that the fabric face upstream to the fluid stream during processing is adjacent the plate and the selected entangled area is placed over a plate-hole having a diameter not more than 75% of the diameter of the n-

tangled area being tested. For testing entangled areas which are smaller in diameter than about 1.33X the needle-shank diameter, the entangled area may be placed over a plate-hole having a diameter slightly larger than that of the needle shank. A light source under the plate-hole and suitable optical magnification are used to assist in achieving the correct placement over the hole. The needle is placed vertically above the entangled area in a central position. The weight of the needle assembly is then allowed to rest on the entangled area by lightly supporting the assembly with the hand to keep the needle vertical. Record is kept of whether it is penetrated or not, using 25 tests as the standard sample. The impenetrability rating (I) is the ratio of the number of entangled areas not penetrated to the total number tested. This test allows for the inevitable variation in entanglement in the various areas in a given sample and provides the average fraction of representative entangled areas which will not be penetrated. The highly entangled areas in the products of the present invention have an impenetrability rating of at least 0.5. Entanglement frequency, (f_{d1}), is determined from strip tensile strength data.

Two specimens are cut in the same direction from the same sample for strip tensile measurement. One sample is one-fifth the width of the other. The strengths of the two, F_1 and F_2, are determined. It is found that the strength ratio F_1/F_2 is not equal to w_1/w_2 (F_2 and w_2 correspond to the wider sample).

A non-stress-bearing border zone (D_1) at the edges of each specimen is postulated, which zone is ineffective in carrying stress. Thus, considering only stress-bearing width,

$$\frac{F_1}{F_2} = \frac{w_1 - 2\,D_1}{w_2 - 2\,D_1}$$

This distance (D_1) is the average distance required for a fiber in the fabric to become completely entangled. The reciprocal of D_1, f_{d1} is the number of times per unit length a fiber

segment is operative in an entangled region.

In practice, strip widths $w_1 \sim 0.2$ inch (0.508 cm) and $w_2 \sim 1$ inch (2.54 cm) are used for initial tests (always using integer number of unit cells if there is any pattern). If f turns out to be small (i.e., $<$ 20 per inch) (7.9/cm), the test should be repeated with wider strips (say, 0.4 and 2 in) (1.02 and 5.08 cm). If f turns out to be rather large (say, over 100/in) (40/cm), a smaller w_2 (say, 0.1 in) (0.25 cm) will give more accurate results. A 1.5 inch (3.8 cm) gauge length is used, with an elongation rate of 67% per minute.

Entanglement completeness (C) is determined from strip tensile strength data.

Two strips of equal width [preferably 1 inch (2.54 cm)] are cut in the same direction from the same sample but of different length. The tensile strength of both strips is determined but at different gauge length; one gauge length is one-tenth the gauge length of the other [preferably 0.15 in (0.38 cm) and 1.5 inches (3.8 cm), respectively]. For fabrics consisting only of short fibers, the shorter strip is 0.05 inches long.

The ratio of the force to break the longer strip (F_d) to the force to break the shorter strip (F_s) is a measure of the entanglement completeness.

With the short gauge length, an appreciable proportion of the fibers are caught jaw-to-jaw and must be broken, while with longer gauge length the fibers may slip out of the fabric without breaking if the fabric is not completely entangled. A low ratio F_d/F_s indicates such slippage is occurring and that entanglement is not complete.

The 45/90/135 number is best determined by spatially filtering the optical diffraction pattern of sections of fabrics.

First, a sample of fabric is embedded in a clear plastic of index of refraction at 6328 A° differing by at least .01 from the index of refraction of the fibers in the fabric. An

axis is fixed arbitrarily on the fabric face and a second axis 90° to the first is then drawn. Sixty consecutive cross-sections are then cut along each axis. The sections are 30 microns thick, 4 mm wide and 10 mm long. Every other section is discarded and those sixty remaining are each mounted between two glass slides held apart by glass spacers. The same plastic in which the samples are embedded is used for mounting.

The scanning apparatus consists of

(1) a source of a collimated beam of 6328 A° wave length light which is used to illuminate a 1 mm diameter area of sample section. A typical source is a helium-neon laser operating in the TEM_{00} mode.

(2) a lens.

(3) a thin opaque plate with a narrow slit which is partially blocked by a relatively wide opague strip perpendicular to the slit.

(4) a second lens similar to the first.

(5) a photocell.

(6) a recorder to pick up the signal from the photocell.

The focal length of the lenses and the slit size are in proper proportion such that the photocell signal from a straight fiber segment goes from maximum to 1/2 value when the fiber is rotated $9 \pm 3°$ from the angle at which maximum signal occurs.

To effect the measurement the cross-section is placed one focal length from one of the lenses. One focal length on the other side of that lens is placed the thin plate with the slit. That location is also one focal length from the second lens which is located on the other side of the slit. On the other side of the second lens and one focal length from it is placed the photocell.

The light beam is thus directed through the cross-section, first lens, on the strip over the slit (and an equal distance fr m th edges of the slit), through the second lens and

to the photocell.

A section is scanned by orienting the slit parallel to the length of the section and the section is moved along its length until the region is located where the greatest signal is obtained from the photocell (regions near the edges of the section are avoided). The angular orientation at that region is obtained by rotating the slit through 180° and recording the signal from the photocell as a function of the angle the slit makes with the width of the cross-section. The area under the curve of the recorder signal vs. angle is a function of the angular position of the fibers in the region measured. The greater the area at any angle, the more fibers are aligned at that angle. The angles are determined with an accuracy of ± 6° and a precision of ±1°. The relative light intensity is determined with an accuracy of ± 10% and a precision of ± 2%.

"S", a structural measure of entanglement and cooperation is defined by the following equation:

$$S = pd/L.$$

The fiber concentration factor, p, is the ratio of the weight per unit area of the entangled portion (W_1) to the weight per unit area of the entire fabric (W_2).

W_1 and W_2 are determined from the fabric sample by direct measurement. For W_1, ten specimens are cut from the entangled mass or representative portion thereof from the fabric with a suitable die. The area of the mass then corresponds to the area of the die. All ten specimens are weighed at one time on a suitable microbalance. An average unit weight (W_1) is calculated.

The density (d) of the entangled mass can be measured by calculating the volumes of the cut-out specimens mentioned above. To do this, the specimens are mounted axially on broaches and are photographed at 20X to provide a cross-sectional view. The cross-section thus photographed may be irregular in shape.

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If so, the shape is approximated with rectangles and/or triangles. The shapes are then measured and, using the appropriate geometric formulas, the corresponding volumes are calculated. The total weight of the ten specimens is then divided by the sum of the ten volumes to give the average density (d) in grams/cm^3 of the entangled area.

The process of this Supplementary Disclosure may be more thoroughly understood by referring to the accompanying drawings wherein:

Fig. 13 is a chart for estimating free length,

Fig. 14 is a chart showing jet velocities.

The average-free-length factor (L) of the fibers is estimated by direct observation (under a microscope) of the fibers outside the entangled area and comparison to a set of standards. The fiber is observed both in plan view and in cross-sectional view. The five ratings used as standards and the corresponding curvatures and free lengths are shown in Figure 13. If, for example, the fibers on the average are visually estimated to have a curvature such that the ratio of the deviation from straightness (h) to the half-length in the group observed (hl) is about 0.5, then a rating of 3 is assigned. Such estimates are made three times independently, and averaged both in the plane of the fabric and normal to or out of the plane (cross-section). The two estimates are then combined geometrically by taking the square root of half the sum of the squares of the two ratings. If L_1 is the estimated in-plane rating and L_2 is the estimated out-of-plane rating, the average-free-length factor (L) is:

$$L = \sqrt{\frac{L_1^2 + L_2^2}{2}}$$

It is observed that structures made from straight (i.e., non-crimped or noncurled) fibers do not have ratings of one (corresponding to no curvature). An appropriate rating which may be used for structures made from straight fibers is $L = 1.4$. Simi-

larly, it is observed that the rating for samples made from conventional staple fibers or low crimp continuous filaments ranges from 1.8 to 2.5. For such fibers, an average rating of L = 2.1 may be used. For highly crimped fibers, the actual measurement value of L should be used.

In a further preferred embodiment the fibers in the region of highest entanglement are substantially inseparable.

By inseparable is meant that the fibers or filaments are so entangled with each other in the regions of fiber entanglement that a substantial number of fibers break as they are separated from the entangled mass.

When the 5% secant modulus of a sheet structure (the secant modulus at 5% on the stress-strain strip tensile breaking curve) is below 10.6 gm/cm//gm/m^2, the structure has exceptionally good compliance (the ability of a structure to conform to a curved surface) for apparel fabric end uses. The preferred structure also has a cantilever bending length (ASTM Test 1288-55T) of less than 1.5 cm and, therefore, has adequate flexibility for such uses. Similarly, a thickness of less than 0.020 inch (0.051 cm) is preferred to yield an apparel fabric-like density at weights of less than 170 gm/m^2.

The preferred product embodiment possesses both high flexibility and compliance. At the same time, these preferred structures exhibit tensile strength $>$ 10.6 gm/cm//gm/m^2 and tear strength $>$ 9.4 gm/gm/m^2 in the absence of binder or self-bonds.

The structures of this invention are useful in all textile uses such as draperies, industrial fabrics, garments, absorbent fabrics and the like.

It is understood that this product may be bonded, if desired, or treated with normal textile finishes, dyed or subjected to any or all finishing treatments. Such resultant product is still within the scope of the invention if the product has the characteristic structure described.

The following Examples, in which all percentages are by weight unless otherwise indicated, are meant to illustrate the invention and not limit it in any way. Values of orifice velocity referred to in the Examples are estimated from Figure 14 which is based on numerous measurements over the indicated range.

Figure 14 shows the estimated orifice velocity (based on a discharge coefficient of 0.62) for 3, 5 and 7 mil jet orifices.

EXAMPLE XXIII

A 2.9 oz/yd^2 (98 gm/m^2) web of randomly arranged staple fiber containing 50% 1.5 inch (3.8 cm), 1.5 dpf acrylic fiber and 50% 0.25 inch (0.64 cm) 1.5 dpf rayon was placed on a flat supporting member and passed under water jet streams issuing from 0.007-inch (0.18 cm) diameter orifices located 0.05 inches (0.127 cm) apart over a width of 21 inches (53.3 cm). The water jet stream temperature was 60° C. The jet orifices were oscillated at approximately 300 oscillations per minute. The web was passed under the jet streams approximately 0.5 inch (1.27 cm) from the orifice at a belt speed of 2 yd/min (3.1 cm/sec). A coarse meshed top screen was over the web to prevent air turbulence from destroying web uniformity.

Processing conditions were as follows: one pass at 500 psi (35.2 kg/cm^2), one pass at 1500 psi (106 kg/cm^2). The web was then flipped so that the upstream side now rested on the supporting member and reprocessed with two passes at 1500 psi (106 kg/cm^2). All passes were run with the coarse mesh top screen. The maximum processing conditions correspond to an orifice velocity of about 460 ft/sec (14,000 cm/sec) and an impact pressure greater than 2500 ft-lb/sec^2-in^2 (108 kg-m/sec^2-cm^2). The nonforaminous product has an average strength in all directions of 3.8 lb/in//oz/yd^2 (20 g/cm//g/m^2). The impenetrability rating (I) was measured and found to be (one) 1; the 45/90/135 number is 23, f is 26/inch (10.2/cm) and C is one (1).

EXAMPLE XXIV

A commercial 19 oz/yd^2 needle punched 100% polyester felt has a 45/90/135 number of 1, the (I) factor is 1.0, and f is less than 20/inch, showing that this is not the product of the present invention.

EXAMPLE XXV

A web of random staple fibers containing 50% acrylic fiber of 1-1/2 dpf, 1/4" long and 50% rayon of 1-1/2 dpf, 1/4" long was placed on a supporting member and treated hydraulically with jet streams issuing from 7 mil diameter jet orifices spaced at 20/inch at a distance of 3/8" from the orifices. The treatment was as follows:

Passes at 2 y.p.m. (1.83 metres/min.)	Pressure
1	200 psi
4	500
2	750
sample	flipped
1	500
sample	flipped
1	500

9 passes

The nonforaminous product had a tensile strength of 5.82 lb/in/oz/yd^2 in the machine direction and 2.29 lb/in/oz/yd^2 in the cross direction. It had a 45/90/135 number of 17, and an I rating greater than 0.5 and f is greater than 20, showing that this is the product of this invention.

EXAMPLE XXVI

A 2.5 oz/yd^2 (85 gm/m^2) web of randomly arranged staple fiber consisting of 50% 1.5 inch (3.8 cm), 1.5 dpf (0.17 tex) acrylic fiber and 50% 0.25 inch (0.64 cm) 1.5 dpf (0.17 tex) rayon was placed on a flat supporting member and passed under water jet streams issuing from 0.007 inch (0.018 cm) diameter orifices located 0.05 inches (0.127 cm) apart over a width of 21 inches (53.3 cm). The water jet stream temperature was 60° C. The jet orifices were not oscillated. The web was passed under the jet streams approximately 3/8 inches (0.95 cm) from the ori-

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fice at a speed of 2 yd/min (3.1 cm/sec). Processing conditions were as follows: two passes at 500 psi (35.2 kg/cm^2), one pass at 1000 psi (70 kg/cm^2). The maximum processing conditions correspond to an orifice velocity of about 370 ft/sec (11,100 cm/sec) and a momentum-flux greater than 7000 ft-lb/in^2-sec^2 (151 kg-m/sec^2-cm^2). The product has an average strength in all directions of 3.8 lb/in//oz/yd^2 (20 gm/cm//gm/m^2). The fabric was nonforaminous and had no visible pattern. The impenetrability rating (I) is 1 (one), the (C) factor is 0.9 and f is 20/inch (7.9/cm).

EXAMPLE XXVII

A 4.0 oz/yd^2 (135 gm/m^2) web of randomly arranged staple fiber consisting of 50% 1.5 inch (3.8 cm), 1.5 dpf (0.17 tex) acrylic fiber and 50% 0.25 inch (0.64 cm) 1.5 dpf (0.17 tex) rayon was placed on a flat supporting member and passed under water jet streams issuing from 0.007 inch (0.0177 cm) diameter orifices located 0.05 inch (0.127 cm) apart over a width of 21 inches (53.3 cm). The water jet stream temperature was 60° C. The jet orifices were not oscillated. The web was passed under the jet streams approximately 3/8 inches (0.95 cm) from the orifice at a speed of 2 yd/min (3.1 cm/sec). Processing conditions were as follows: one pass at 500 psi (35.2 kg/cm^2), one pass at 1000 psi(70 kg/cm^2). The web was then flipped so that the upstream side now rested on the supporting member and reprocessed with one pass at 1000 psi (70 kg/cm^2). All passes were run without any coarse mesh top screen. The maximum processing conditions correspond to an orifice velocity of about 370 ft/sec (11,100 cm/sec) and a momentum-flux of approximately 7000 ft-lb/sec^2-in^2 (151 kg-m/sec^2-cm^2). The product has an average strength in all directions of 2.4 lb/in//oz/yd^2 (12.5 gm/cm//gm/m^2). The fabric was nonforaminous having no visible pattern. The impenetrability rating (I) is 1 (one), the (C) factor is 0.9 and f is 37/inch (14.5/cm).

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. The process for hydraulically treating sheet material composed of textile filaments which comprises projecting a fine, columnar stream of a non-compressible fluid against the surface of said sheet material with sufficient force to drive portions of individual surface filaments a substantial distance into the sheet, directing the stream along a given path until a three-dimensional interentanglement of filaments is produced in the path of the stream, and changing the relative positions of the stream and sheet to extend the interentanglement to other parts of the sheet.

2. A process as defined in claim 1 wherein the process is used to produce a seam-like linear bond.

3. A process as defined in claim 2 wherein a plurality of crossing linear bonds are produced to provide a quilted structure.

4. A process as defined in claim 1 wherein the sheet comprises a layer of loosely assembled filaments which is treated over substantially the entire surface to provide a non-woven fabric.

5. A process as defined in claim 1 wherein the sheet material is a woven fabric and is treated over substantially the entire surface to increase the fabric covering power.

6. A process as defined in claim 1 wherein the sheet material is a knitted fabric and is treated over substantially the entire surface to increase the fabric covering power.

7. In the process of producing felt-like fabrics wherein interfilament entanglement is conventionally accomplished by mechanical needling, the improvement of hydraulically interentangling filaments throughout the fabric with needle-like columnar streams

of a non-compressible fluid projected at high velocity into the fabric.

8. In the process of producing a non-woven fabric from a loose fibrous batt, the improvement of hydraulically interentangling fibers of the batt with high-velocity columnar streams of sufficient fineness to avoid permanently separating groups of fibers, and traversing the streams over the surface to produce three-dimensional entanglement throughout the fabric.

9. The process for converting fibrous material into yarn which comprises laying the fibrous material down in the form of a random batt, hydraulically stitching the batt to form continuously united parallel seams by projecting fine, columnar streams of a non-compressible fluid into the batt with sufficient force to interentangle fibers through the thickness of the batt, and then cutting the batt between the seams.

10. The process of hydraulically stitching a fibrous batt to a woven fabric which comprises superimposing the batt on the fabric and projecting fine, columnar streams of a non-compressible fluid into the batt with sufficient force to drive fibers of the batt into interentanglement with the fabric structure.

11. The process for converting bulk fibrous materials into non-woven fabrics which comprises depositing a loose layer of textile fibers on a foraminous surface, directing a plurality of columnar liquid streams against said layer under sufficient pressure to penetrate and effect an interentangling integration of the fibers in the layer, progressively advancing the layer and reciprocating at least one of the streams across the layer to produce closely spaced seams of interentangled fibers in both directions of the layer.

12. The process for improving the appearance and covering power of woven fabric which comprises supporting the fabric on a foraminous surface, directing a plurality of columnar liquid streams against the fabric at an oblique angle to the fabric yarns under sufficient pressure to penetrate and effect an interentangling integration of fibers in the fabric, advancing the fabric under the streams and reciprocating the streams to treat substantially the entire surface of the fabric.

13. A process as defined in claim 12 wherein the fabric is treated on the bias.

14. A process as defined in claim 12 wherein the fabric is progressed continuously under a row of streams aligned at an oblique angle with respect to the direction of travel of the fabric with the individual streams angled toward the oncoming fabric.

woven fabric

15. A fibrous sheet material having individual fibrous elements intertwined, tangled and interlaced in an interentangled relationship with other fibrous elements in all dimensions of the structure to provide a coherent fabric free from openings.

16. A non-woven fabric of fibrous sheet material having individual fibrous elements intertwined, tangled and interlaced in an interentangled relationship with other fibrous elements in all dimensions of the structure to provide seams and with other fibrous elements substantially uniformly distributed throughout the remainder of the fabric.

17. A non-woven fabric as defined in claim 16 wherein the interentangled fibrous elements provide linear seams.

18. A non-woven fabric as defined in claim 17 wherein the seams are in substantially parallel rows.

19. A non-woven fabric as defined in claim 17 wherein the seams extend in two directions t provide a quilt-like structure.

20. A non-woven fabric as defined in claim 16 wherein the seams are discontinuous.

21. A non-woven fabric as defined in claim 16 composed of at least one fibrous web united to a crossed-warp of yarns by said seams to provide a strong, coherent structure.

22. A non-woven fabric as defined in claim 21 composed of continuous filaments.

23. A non-woven fabric as defined in claim 21 wherein the fibrous web is composed of staple fibers.

24. A non-woven fabric as defined in claim 21 wherein the crossed-warp is composed of elastic yarn.

25. A composite fibrous sheet material of woven fabric and non-woven fibrous sheet material secured thereto by individual fibrous elements intertwined, tangled and interlaced in an interentangled relationship with other fibrous elements in all dimensions of the structure to provide seams.

CLAIMS SUPPORTED BY THE SUPPLEMENTARY DISCLOSURE

26. A nonforaminous nonwoven fibrous sheet comprising fibers or filaments or mixtures thereof characterized by having fibers or filaments therein so entangled with other fibers or filaments that

(a) the impenetrability rating of the highly entangled regions is at least 0.5 when the sheet is in the bond free state, and

(b) the entanglement frequency (f) is at least 20/in (7.9/cm) when determined in the bond free state.

27. The product of Claim 26 characterized in that the entanglement completeness (C) is at least 0.7 when measured in the bond free state.

28. The product of claims 26 and 27 wherein the 45/90/135 number is at least 10.

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29. The product of claim 26 wherein the entangled regions are discrete areas and define a pattern.

30. The product of claim 29 wherein the structural measure of fiber entanglem nt in the regions of highest fiber entanglement and fiber cooperation in the structure, (S), is at least 0.1 when the sheet is in the bond free state.

31. The product of claims 26, 27 and 29 wherein the unit weight is not more than 170 gm/m^2.

32. The product of claim 26 characterized in that the 5% secant modulus in at least one direction is less than 10.6 gm/cm//gm/m^2 and a cantilever bending length in at least one direction is less than 2.0 cm.

33. The product of claim 32 characterized in that the strip tensile strength in one direction is greater than 10.6 gm/cm//gm/m^2 and the tongue tear strength in at least one direction is greater than 9.4 gm//gm/m^2, both measurements made in the absence of binder.

34. The process of preparing a nonforaminous fibrous sheet material characterized by subjecting a fibrous web on a supporting member to a fine columnar stream of a non-compressible fluid issuing from an orifice to cause fibers or filaments to move relative to each other by the impingement force of the stream, said stream having a momentum-flux of at least 6 kg-m/sec^2-cm^2 at the point of impingement on to the web.

35. The process of claim 34 wherein the orifice velocity of the stream is greater than 6,000 cm/sec.

36. The process of claims 34 and 35 wherein the web and fluid orifice move relative to each other.

37. The process of claims 34 and 35 characterized in that

(a) the fibers or filaments in the fibrous webs have the latent ability to shrink, crimp or elongate and

(b) a subsequent treatment comprises heating the filaments to cause, respectively, shrinkage, crimping or spontaneous longation f the fibers or filaments.

38. The process of claims 34 and 35 characterized in that the divergence angle of the fluid stream is less than 3°.

39. The product of any f Claims 26, 27 or 29 wherein the entanglement frequency "f" is at least 30/inch (11.8/cm) when determined in the bond free state.

40. The product of Claim 29 wherein the entanglement frequency "f" is at least 30/inch (11.8/cm) when determined in the bond free state and the structural measure of fiber entanglement in the region of highest fiber entanglement and fiber cooperation in the structure, (S) is at least 0.1 when the sheet is in the bond free state.

41. The product of Claim 26 wherein the entanglement frequency "f" is at least 30/inch (11.8/cm) when determined in the bond free state and characterized in that the 5% secant modulus in at least one direction is less than 10.6 $gm/cm//gm/m^2$ and a cantilever bending length in at least one direction is less than 2.0 cm.

42. The product of Claim 32 wherein the entanglement frequency "f" is at least 30/inch (11.8/cm) when determined in the bond free state and characterized in that the strip tensile strength in one direction is greater than 10.6 $gm/cm//gm/m^2$ and the tongue tear strength in at least one direction is greater than 9.4 $gm//gm/m^2$, both measurements made in the absence of binder.

43. The product of any of Claims 26, 27 or 29 wherein the fibrous matter of the sheet is comprised of filaments.

44. The product of Claim 29 wherein the fibrous matter of the sheet is comprised of filaments and the structural measure of fiber entanglement in the regions of highest fiber entanglement and fiber cooperation in the structure, (S) is at least 0.1 when the sheet is in the bond free state.

45. The product of Claim 26 wherein the fibrous matter of the sheet is comprised of filaments and characterized in that the 5% secant modulus in at least one direction is less than 10.6 $gm/cm//gm/m^2$ and a cantilever bending length in at least one direction i• less than 2.0 cm.

46. The product of Claim 32 wherein the fibrous matter of the sheet is comprised of filaments and characterized in that the strip tensile strength in one direction is greater than 10.6 gm/cm//gm/m^2 and the tongue tear strength in at least one direction is greater than 9.4 gm//gm/m^2, both measurements made in the absence of binder.

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JET STITCHING OF BATT

FIG. 1

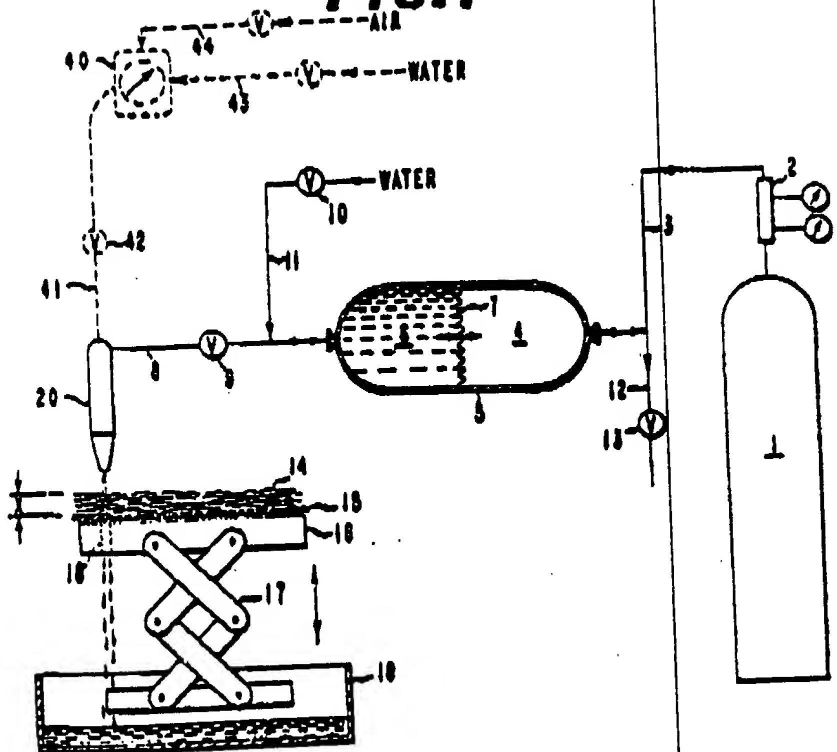

FIG. 2a

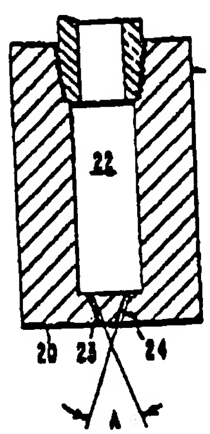

FIG. 2b

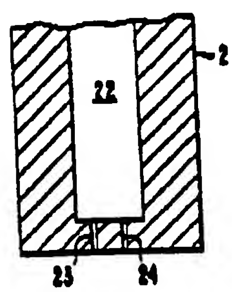

FIG. 2c

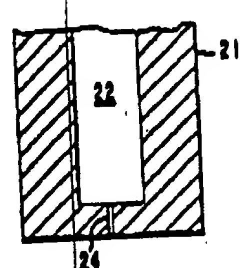

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FIG. 3

FIG. 4

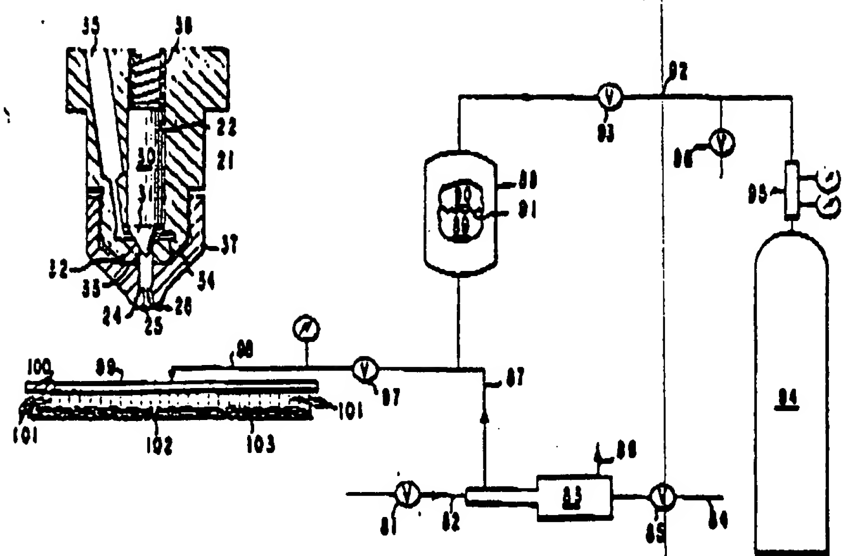


FIG. 5

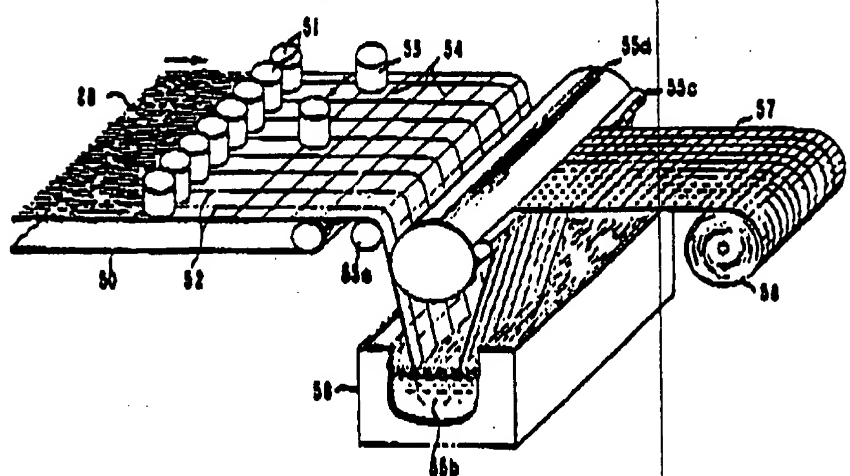


FIG. 6

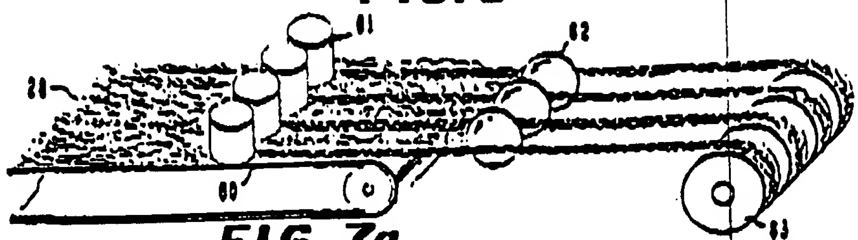


FIG. 7a

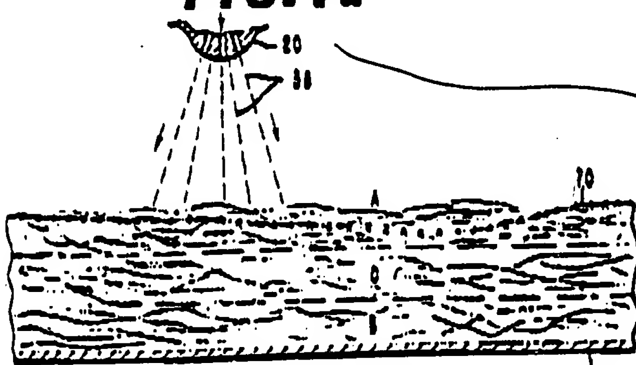


FIG. 7b

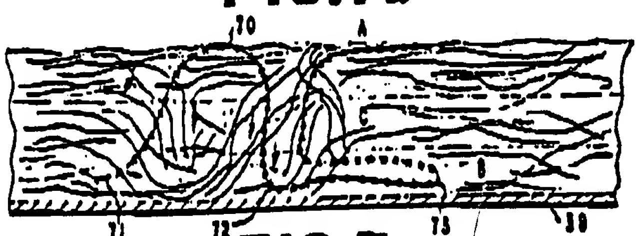
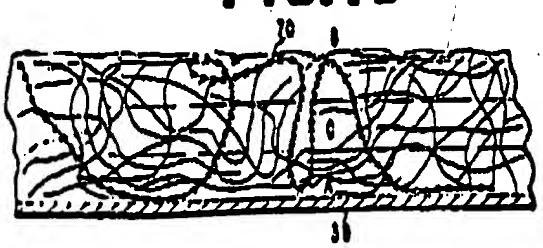


FIG. 7c



#20 is Defined as any one of a variety of nozzles - What kind of nozzle does 7a show